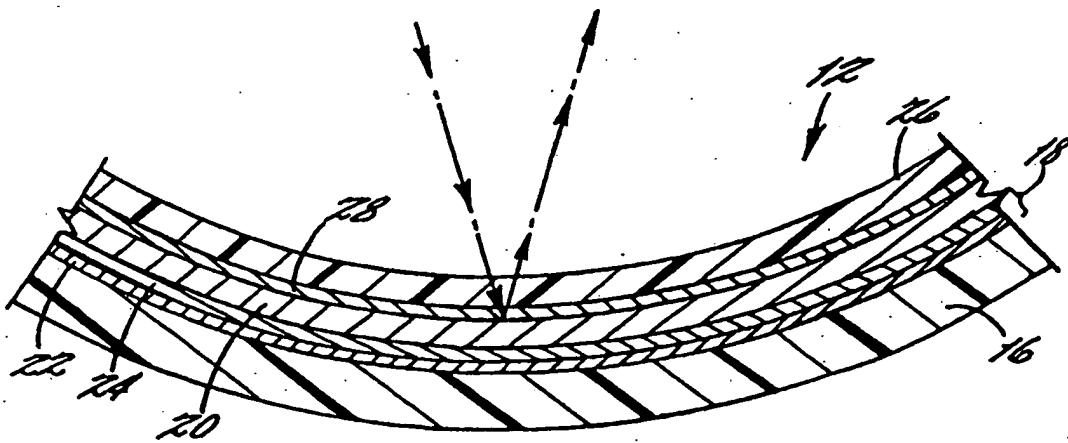




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(71) Applicant (for all designated States except US): McDONNELL DOUGLAS CORPORATION [US/US]; P.O. Box 516, St. Louis, MO 63166-0516 (US).		Published With international search report.
(72) Inventors; and		
(75) Inventors/Applicants (for US only): FERRANTE, Ronald, Alfred [US/US]; 2531 MacBeth Avenue, Corona, CA 91720 (US). OTT, Rudolph, Herman [US/US]; R.R. 1, Box 92, Batchtown, IL 62006 (US).		
(74) Agents: GOSNELL, Guy, R. et al.; Bell Seltzer Intellectual Property Law Group, Alston & Bird LLP, P.O. Drawer 34009, Charlotte, NC 28234 (US).		

(54) Title: REFLECTOR AND ASSOCIATED LIGHT ASSEMBLY



## (57) Abstract

The reflector (10) includes a substrate (16) and a plurality of intermediate layers which include at least one bonding layer (18) disposed upon the substrate and a metallic reflectance layer (20) disposed upon the bonding layer. The bonding layer includes a first dielectric layer (22), such as aluminum oxide ( $Al_2O_3$ ), for bonding or adhering the metallic reflectance layer to the substrate. The reflectance layer is preferably comprised of a silver material which reflects a high percentage of the incident light. In addition, the reflector can include a protective layer (26), such as a layer of Leybold Mark 3 material, for protecting the underlying bonding and reflectance layers, such as from tarnishing and other environmental degradation. As a result, the reflector provides a relatively high level of reflectance which does not degrade over time since the reflectance layer remains tightly adhered to the substrate and since the reflector is protected from tarnishing. In addition, the reflector can be curved in order to further focus the reflected light.

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## REFLECTOR AND ASSOCIATED LIGHT ASSEMBLY

### BACKGROUND OF THE INVENTION

The present invention relates generally to reflectors and associated light assemblies and, more particularly, to curved reflectors having a relatively high reflectance.

Lighting reflectors are employed in a variety of applications to enhance the resulting brightness provided by a light source. For example, aircraft and spacecraft include a number of reflectors both 5 externally and internally, such as within a cockpit display or a helmet mounted display. In addition, flash jet paint removal systems, such as described by U.S. Patent No. 5,328,517, can include one or more reflectors for increasing the intensity of the light focused upon the painted surface of an aircraft. Most 10 commonly, automobiles and other vehicles typically include a number of reflectors in order to increase the brightness of the head lamps or other exterior or interior lighting systems.

Conventional lighting reflectors are 20 typically formed of aluminum or include an aluminum coated surface to enhance the resulting brightness. While an aluminum or aluminum coated surface reflects approximately 80 to 90 percent of the light energy, the reflector absorbs the remainder of the light energy as heat, thereby creating significant inefficiencies. As 25 a result, more sophisticated reflectors have been

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developed to reflect a greater percentage of the incident light.

For example, reflectors which include a plurality of dielectric coating layers have been 5 developed. In order to provide sufficient reflectance, however, the thickness of each dielectric layer must be precisely controlled, thereby increasing the complexity of the fabrication process. In addition, reflectors must oftentimes be curved in order to properly direct 10 the reflected light. Accordingly, it is even more difficult, if not impossible, to precisely control the thickness of each dielectric layer of a curved dielectric coated reflector.

Reflectors which do not include dielectric 15 layers, but which include silver based coatings have also been developed in order to provide improved reflection efficiency. While reflectors which include silver based coatings typically require less precision with respect to the thickness of the various layers, 20 reflectors which include silver based coatings commonly have poor adhesion. As a result, the silver based coatings may release, in whole or in part, from the underlying substrate, thereby significantly impairing the reflectance of the reflector. In addition, 25 reflectors which include silver based coatings typically tarnish following exposure to air over time, thereby further diminishing the performance of the reflector.

Therefore, while it would be desirable for a 30 lighting reflector to reflect a greater percentage of the incident light than conventional aluminum or aluminum coated reflectors, the reflectors currently available all suffer from several deficiencies. For example, dielectric coated reflectors require the 35 dielectric layers to have a specific thickness, thereby complicating the fabrication process particularly with respect to the fabrication of curved reflectors.

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Moreover, reflectors which do not include dielectric layers, but which include silver based coatings typically tarnish and suffer from poor adhesion, thereby impairing the performance of these reflectors.

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#### SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide an improved reflector which reflects a high percentage of the incident light.

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It is another object of the invention to provide a reflector which is relatively insensitive to variations in the thickness of the individual coating layers.

15

It is a further object of the invention to provide a reflector which includes coating layers that are tightly adhered to the underlying substrate.

It is yet another object of the invention to provide a curved reflector which can be easily fabricated.

20

It is still another object of the invention to provide a reflector which includes a silver reflectance layer which does not readily tarnish.

25

These and other objects are provided, according to the present invention, by a reflector which includes a substrate and a plurality of intermediate layers including at least one bonding layer disposed upon the substrate and a metallic reflectance layer disposed upon the bonding layer. The bonding layer includes a first dielectric layer, such as aluminum oxide ( $Al_2O_3$ ), for bonding or adhering the metallic reflectance layer to the substrate. The reflectance layer is preferably comprised of a silver material which reflects a high percentage of the incident light. In addition, the reflector of the present invention can include a protective layer, such as a layer of Leybold Mark 3 material, for protecting the underlying bonding and reflectance layers, such as

from tarnishing and other environmental degradation. As a result, the reflector of the present invention provides a relatively high level of reflectance which does not degrade over time since the reflectance layer 5 remains tightly adhered to the substrate and since the reflector is protected from tarnishing.

In order to further improve the adherence of the reflectance layer to the substrate, the bonding layers can include a copper (Cu) layer disposed between 10 the first dielectric layer and the reflectance layer. In addition, the reflector of one advantageous embodiment includes a second dielectric layer between the reflectance layer and the protective layer in order to adhere the protective layer thereto.

15 Since the metallic reflectance layer reflects the incident light, the reflector of the present invention is relatively insensitive to variations in the respective thicknesses of the bonding and reflectance layers. However, the reflectance layer is 20 preferably thicker than each of said bonding layers. In particular, the reflector of one advantageous embodiment includes bonding and reflectance layers which have respective predetermined thicknesses, i.e., optical thicknesses, based upon the predetermined 25 wavelength  $\lambda$  of light which the reflectance coating preferentially reflects. For example, the predetermined thickness of the reflectance coating preferably equals  $\frac{k\lambda}{4}$  for a positive odd integer  $k$ ,

while the predetermined thickness of each bonding layer 30 preferably equals  $\frac{(2m + 1)\lambda}{32}$  for a positive whole number  $m$ .

As a result, the reflector of this embodiment can be tailored to preferentially reflect light of a predetermined wavelength  $\lambda$  by controlling the respective thicknesses of the bonding and reflectance 35 layers.

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Although the reflector of one advantageous embodiment includes bonding and reflectance layers which have respective predetermined thicknesses, the reflector of the present invention remains relatively 5 insensitive to variations in the thicknesses of the bonding and reflectance layers. Thus, the reflector can be curved since the bonding and reflectance layers can be readily deposited upon a curved substrate. As a 10 result, the curved reflector of this embodiment of the present invention can form a portion of a lighting assembly which also includes a light source disposed adjacent the concave surface of the curved reflector.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a lighting 15 assembly including a curved reflector according to one advantageous embodiment of the present invention.

Figure 2 is a cross-sectional view of the curved reflector illustrated in Figure 1 which depicts the various bonding, reflectance and protective layers.

Figure 3 is a graph illustrating the reflectance of a reflector according to one embodiment 20 of the present invention as a function of wavelength in comparison to the reflectance of a conventional aluminum coated reflector as a function of wavelength.

#### DETAILED DESCRIPTION OF THE INVENTION

Various methods and apparatus embodiments of the invention are set forth below. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiment set forth 30 herein. To the contrary, the invention includes numerous alternatives, modifications, and equivalents as will become apparent from consideration of the present specification including the drawings, the foregoing discussion, and the following detailed 35 description. Like numbers refer to like elements

throughout. In addition, the thicknesses of the various layers have been exaggerated in the drawings for purposes of clarity.

Referring now to Figure 1, a light assembly 5 10 according to the present invention is illustrated. The light assembly can be employed in a variety of applications, such as automotive, aircraft, spacecraft and other applications as will be apparent to those skilled in the art. The light assembly includes a 10 reflector 12 and a light source 14, such as a light bulb. As shown in Figure 1, the reflector can be curved so as to define a concave surface and a convex surface. However, the reflector can have other shapes or can be planar without departing from the spirit and 15 scope of the present invention.

As shown in more detail in Figure 2, the reflector 12 of the present invention includes a substrate 16 and a plurality of intermediate layers disposed upon the substrate. The substrate 16 can be 20 formed of various materials, such as glass, aluminum or a plastic material. While the intermediate layers can be deposited upon the substrate in a variety of manners without departing from the spirit and scope of the present invention, the intermediate layers are 25 typically deposited upon the substrate with a chemical vapor deposition (CVD) process.

The intermediate layers include at least one bonding layer 18 disposed upon the substrate 16 and a reflectance layer 20 disposed upon the bonding layer. 30 The bonding layers include a first dielectric layer 22 which adheres the reflectance layer to the substrate. As a result, the reflectance layer will remain tightly adhered to the substrate such that the reflector 12 of the present invention will continue to provide high 35 reflectance over time. According to one advantageous embodiment, the first dielectric layer is formed of aluminum oxide ( $Al_2O_3$ ). In other embodiments, however,

the bonding layers need not include a dielectric layer, but can include a bonding layer formed of other materials, such as gold.

As shown in Figure 2, the bonding layers 18 of one advantageous embodiment also include a copper (Cu) layer 24 disposed between the first dielectric layer 22 and the reflectance layer 20. The copper layer further adheres the reflectance layer to the first dielectric layer and, in turn, to the substrate 16. While the bonding layers of this advantageous embodiment include a copper layer, the bonding layers can, instead, include a layer formed of gold without departing from the spirit and scope of the present invention. In addition, while the reflector 12 of Figure 2 includes two bonding layers, namely, the first dielectric layer and the copper layer, the reflector can include additional bonding layers, such as additional dielectric layers, without departing from the spirit and scope of the present invention.

The reflector 12 of the present invention preferably includes a reflectance layer 20 formed of a silver (Ag) material. For example, the reflectance layer can be formed of silver and/or silver alloys. However, the reflectance layer can be formed of other metallic materials, such as gold, without departing from the spirit and scope of the present invention. The reflectance layer is designed to reflect light incident thereon. In particular, the reflectance layer can be formed as described hereinbelow such that the light of a predetermined wavelength  $\lambda$  or a predetermined range of wavelengths are preferentially reflected.

The reflector 12 also preferably includes a protective layer 26 disposed upon the reflectance layer 20. The protective layer protects the underlying bonding and reflectance layers from tarnishing and other environmental degradation. The protective layer

is preferably formed of a hard material in order to further protect the underlying bonding and reflectance layers. For example, the protective layer is preferably formed of Leybold Mark 3 (MK3) material which is available from Leybold-Heraeus GmbH of Munich, Germany. However, the protective layer can be formed of other materials, such as  $MgF_2$ , without departing from the spirit and scope of the present invention.

The reflector 12 of one embodiment also includes a second dielectric layer 28 disposed between the reflectance layer 20 and the protective layer 26. The second dielectric layer serves to tightly adhere the protective layer to the reflectance layer and to further protect the reflectance layer. The second dielectric layer is typically formed of the same dielectric material as the first dielectric layer, such as aluminum oxide. However, the second dielectric layer can be formed of other dielectric materials, if so desired. While the illustrated reflector includes a single second dielectric layer, the reflector of this embodiment can include a plurality of dielectric layers between the reflectance layer and the protective layer without departing from the spirit and scope of the present invention.

Since the reflectance layer 20 reflects the incident light, the reflector 12 of the present invention is insensitive to variations in the respective thicknesses of the various layers. Thus, the reflector can be fabricated in a rapid and cost-effective manner with conventional deposition techniques, such as CVD. In addition, the various layers of the reflector can be readily deposited upon a curved substrate 16 in order to form a curved reflector as shown in Figures 1 and 2. Therefore, the reflector of the present invention can be shaped or configured to meet the requirements of the particular application.

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Although the reflector 12 of the present invention is insensitive to variations in the respective thicknesses of the various layers, the predetermined wavelength  $\lambda$  of light preferentially reflected by the reflectance layer 20 is determined by the respective thicknesses of the various layers. In particular, the thickness of the reflectance layer 5 equals  $\frac{k\lambda}{4}$  for a positive odd integer k. Likewise, the thickness of each bonding layer 18, such as the first dielectric layer 22 and the copper layer 24, preferably 10 equals  $\frac{(2m + 1)\lambda}{32}$  for a positive whole number m. Thus, each bonding layer typically has the same predetermined thickness.

As used herein, the thicknesses of the various layers refers to their respective optical thicknesses. Therefore, the wavelength of light which defines, in part, the mathematical relationship between the thicknesses of the various layers and the wavelength of light preferentially reflected therefrom 15 is the wavelength of light within the respective layers. As known to those skilled in the art, the wavelength of light within a layer formed of a material with an index of refraction n is defined as:  $\lambda = \lambda_0/n$  wherein  $\lambda_0$  is the wavelength of light in air.

The reflectance layer 20 is typically thicker than either of the bonding layers 18. For example, a reflector 12 designed to reflect blue light having a wavelength of 400 nm will typically include a reflectance layer having a thickness of 1.33 microns, a 25 first dielectric layer 22 having a thickness of 7.6 nanometers and a copper layer 24 having a thickness of 0.15 microns. Thus, the reflectance layer of one advantageous embodiment is about nine times (or more) 30 as thick as either of the bonding layers.

According to one advantageous embodiment, the protective layer 26 and the second dielectric layer 28 also have respective predetermined thicknesses which are the same as the thicknesses of the reflectance 5 layer 20 and a bonding layer 18, respectively. Thus, the protective layer of this advantageous embodiment is also significantly thicker than any of the bonding layers or the second dielectric layer.

As shown in Figure 3, the reflector 12 of the 10 present invention therefore reflects a greater percentage of the incident light over a wide range of wavelengths than conventional aluminum coated reflectors. Due to the adherence provided by the bonding layers 18, the reflector of the present 15 invention will continue to reflect a very high percentage of the incident light over time since the reflectance layer 20 will remain tightly adhered to the substrate 16. In addition, the protective layer 26 will protect the reflector from tarnishing and other 20 environmental degradation, thereby further improving the lifetime and performance of the reflector.

Many modifications and other embodiments of the present invention will come to the mind of one skilled in the art to which this invention pertains 25 having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the invention is not limited to the specific embodiments disclosed and other embodiments are intended to be included within 30 the scope of the appended claims. Although specific terms have been employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

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THAT WHICH IS CLAIMED IS:

1. A reflector comprising;  
a substrate;  
a plurality of intermediate layers  
disposed upon said substrate, said intermediate layers  
comprising:

5 at least one bonding layer disposed  
upon said substrate, said at least one bonding layer  
comprising a first dielectric layer; and

10 a reflectance layer disposed upon  
said at least one bonding layer such that said at least  
one bonding layer adheres said reflectance layer to  
said substrate, said reflectance layer comprising a  
silver (Ag) material for reflecting light incident upon  
the reflector; and

15 a protective layer disposed upon said  
plurality of intermediate layers for protecting said  
underlying bonding and reflectance layers.

2. A reflector as recited in claim 1  
wherein said first dielectric layer comprises an  
aluminum oxide ( $Al_2O_3$ ) layer disposed adjacent said  
substrate.

3. A reflector as recited in claim 2  
wherein said at least one bonding layer further  
comprises a copper (Cu) layer disposed between said  
aluminum oxide ( $Al_2O_3$ ) layer and said reflectance layer.

4. A reflector as recited in claim 1  
wherein said plurality of intermediate layers further  
comprises a second dielectric layer disposed upon said  
reflectance layer.

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5. A reflector as recited in claim 4 wherein said second dielectric layer comprises an aluminum oxide ( $Al_2O_3$ ) layer.

6. A reflector as recited in claim 1 wherein said protective layer comprises a layer of Leybold Mark 3 material.

7. A reflector as recited in claim 1 wherein each of said bonding layers and said reflectance layer have respective predetermined thicknesses, and wherein said reflectance layer is  
5 thicker than each of said bonding layers.

8. A reflector as recited in claim 7 wherein said reflectance layer is adapted to preferentially reflect light of a predetermined wavelength  $\lambda$ , and wherein the predetermined thickness  
5 of said reflectance layer equals  $\frac{k\lambda}{4}$  for a positive odd integer k.

9. A reflector as recited in claim 7 wherein the predetermined thickness of each of said bonding layers equals  $\frac{(2m + 1)\lambda}{32}$  for a positive whole number m.

10. A reflector comprising:  
a substrate;  
a first dielectric layer disposed upon  
said substrate;

5 a metallic reflectance layer for preferentially reflecting light of a predetermined wavelength, said metallic reflectance layer disposed upon said first dielectric layer such that said first

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10 dielectric layer adheres said metallic reflectance  
layer to said substrate; and  
a second dielectric layer disposed upon  
said metallic reflectance layer.

11. A reflector as recited in claim 10  
further comprising a protective layer disposed upon  
said second dielectric layer for protecting said  
underlying dielectric and metallic reflectance layers.

5 12. A reflector as recited in claim 10  
further comprising a copper (Cu) layer disposed between  
said first dielectric layer and said metallic  
reflectance layer to further adhere said metallic  
reflectance layer to said substrate.

5 13. A reflector as recited in claim 10  
wherein said first and second dielectric layers are  
comprised of aluminum oxide ( $Al_2O_3$ ), and wherein said  
metallic reflectance layer is comprised of a silver  
(Ag) material.

5 14. A reflector as recited in claim 10  
wherein said first and second dielectric layers and  
said metallic reflectance layer have respective  
predetermined thicknesses, and wherein said metallic  
reflectance layer is thicker than each of said first  
and second dielectric layers.

5 15. A reflector as recited in claim 14  
wherein the predetermined thickness of said metallic  
reflectance coating equals  $\frac{k\lambda}{4}$  for a positive odd  
integer k, and wherein the predetermined thickness of  
each of said first and second dielectric layers equals  
 $(2m + 1)\lambda$  for a positive whole number m.

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16. A light assembly comprising:  
a curved substrate;  
a reflector disposed upon said curved  
substrate, said reflector comprising:  
5 at least one bonding layer disposed  
upon said curved substrate; and  
a metallic reflectance layer for  
reflecting light incident thereon, said metallic  
reflectance layer disposed upon said at least one  
10 bonding layer such that said at least one bonding layer  
adheres said reflectance layer to said curved  
substrate; and  
a light source disposed adjacent to said  
curved substrate such that said reflector reflects  
15 light emitted by said light source.

17. A light assembly as recited in  
claim 16 wherein said curved substrate defines a  
concave inner surface, said reflector disposed upon  
said concave inner surface of said curved substrate,  
5 said light source also disposed adjacent said concave  
inner surface of said curved substrate.

18. A light assembly as recited in  
claim 16 wherein said at least one bonding layer  
comprises a first dielectric layer disposed adjacent  
said curved substrate and a copper (Cu) layer disposed  
5 between said first dielectric layer and said metallic  
reflectance layer, and wherein said metallic  
reflectance layer comprises a silver (Ag) material for  
reflecting the light emitted by said light source.

19. A light assembly as recited in  
claim 18 wherein said reflector further comprises:  
a second dielectric layer disposed upon  
said metallic reflectance layer; and

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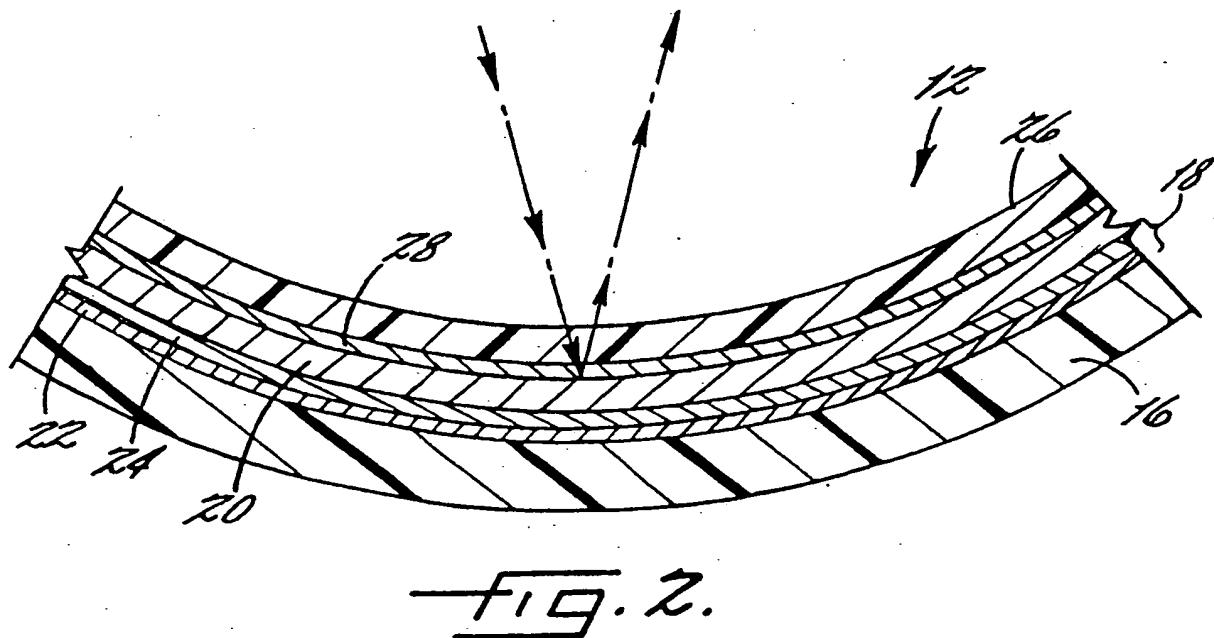
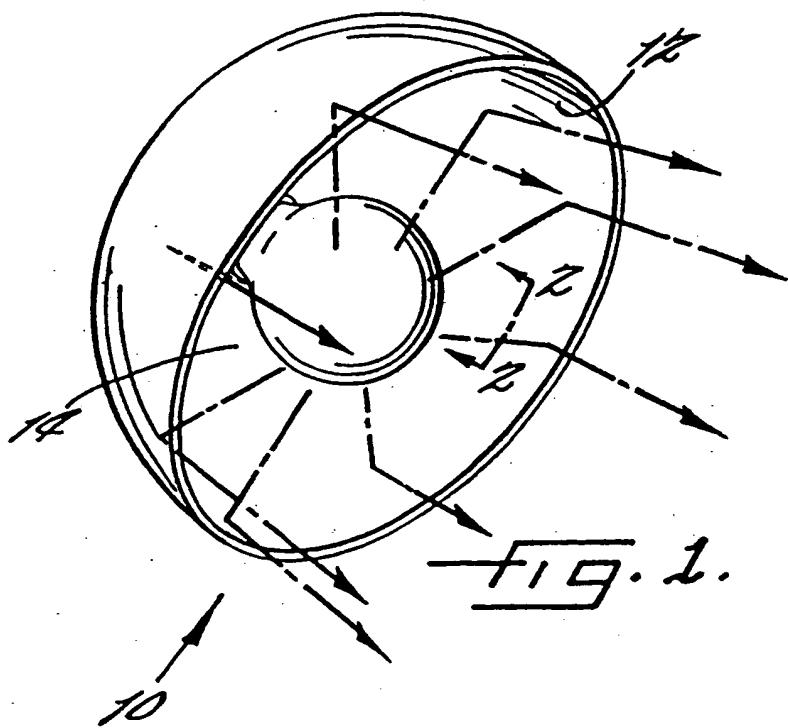
5 a protective layer disposed upon said second dielectric layer for protecting said underlying layers.

20. A light assembly as recited in claim 16 wherein each of said bonding layers and said metallic reflectance layer have respective predetermined thicknesses, and wherein said metallic reflectance layer is thicker than each of said bonding layers.

5 21. A light assembly as recited in claim 21 wherein said light source emits light of a predetermined wavelength  $\lambda$ , wherein said metallic reflectance coating is adapted to preferentially reflect light of the predetermined wavelength  $\lambda$ , and wherein the predetermined thickness of said metallic reflectance coating equals  $\frac{k\lambda}{4}$  for a positive odd integer k.

22. A light assembly as recited in claim 21 wherein the predetermined thickness of each of said bonding layers equals  $\frac{(2m + 1)\lambda}{32}$  for a positive whole number m.

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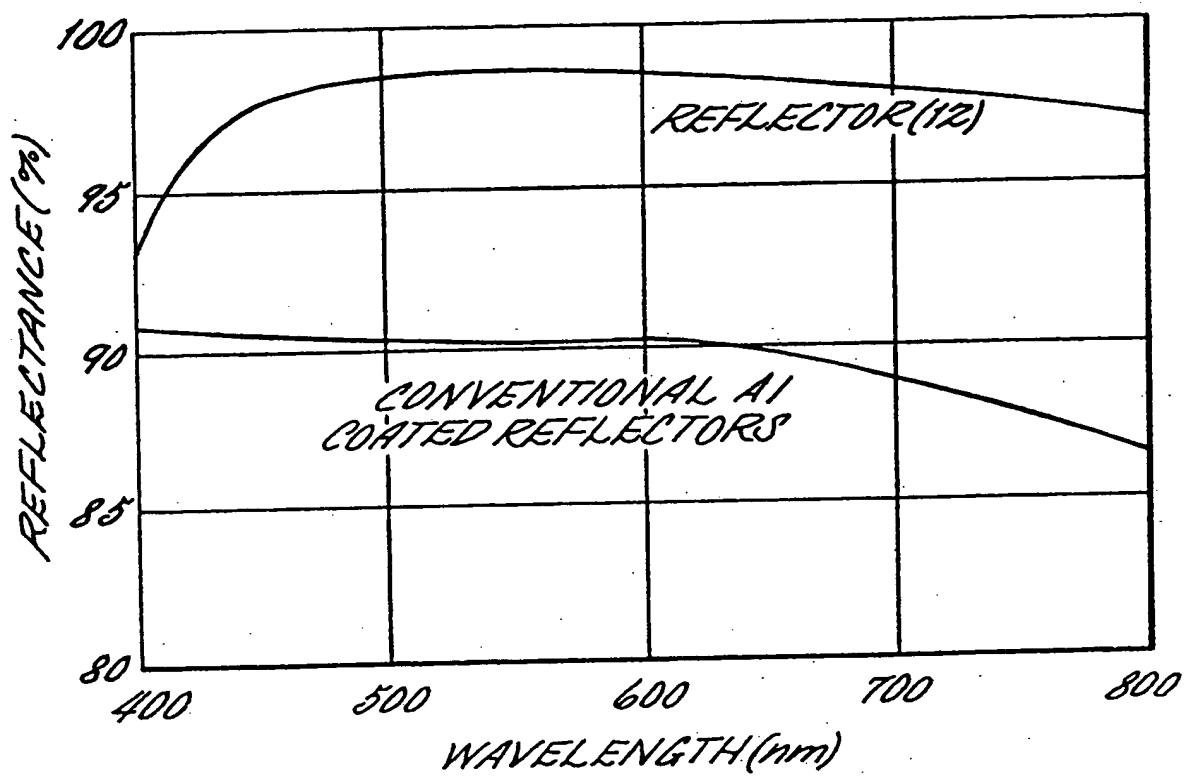


FIG. 3.

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/02392

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 F21V7/22

According to International Patent Classification(IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 516 489 A (MITSUI TOATSU CHEMICALS, INC.) 2 December 1992 see page 3, line 40 - line 50 see page 4, line 8 - line 23 see page 4, line 29 - line 42 see figures 1-3	1,10,11, 16,17,19
X	US 1 953 796 A (CROCKER) 3 April 1934 see page 1, line 79 - line 82 see page 1, line 88 - line 89 see page 2, line 33 - line 47 see page 2, line 103 - line 107 see figures 1-7	1,3,10, 12,16-18

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

15 May 1998

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Name and mailing address of the ISA

European Patent Office, P.O. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl.  
Fax: (+31-70) 340-3016

Authorized officer

De Mas, A

## INTERNATIONAL SEARCH REPORT

International Application No

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Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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